STANDING STOCK ESTIMATES OF BENTHIC FAUNA FOR A LAKE SET IN NORTHWESTERN ONTARIO

1986
ONTARIO FISHERIES
TECHNICAL REPORT SERIES
NO. 21

Ontario
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87-02810/

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STANDING STOCK ESTIMATES OF BENTHIC FAUNA FOR A LAKE SET IN NORTHWESTERN ONTARIO

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ABSTRACT

Cullis, K.I. 1986. Standing stock estimates of benthic fauna for a lake set in Northwestern Ontario. Ont. Fish. Tech. Rep. Ser. No. 21: iii & 20 p.

Benthic samples were collected from 19 lakes, ranging in size from 10 to 953 ha, within a 100 km radius of Thunder Bay, Ontario. Three hundred and sixty (360) benthic samples were collected during the months of July and August 1979, utilizing a systematic, non-random sampling design. Benthic standing stock estimates based on wet weights ranged from 11.1 kg ha^{-1} to 60.5 kg ha^{-1} for the 19 lakes. Total numbers of organisms ranged from 3.0×10^6 ha^{-1} to 2.2×10^8 ha^{-1}. Considerable variation occurred between means of similar sampling transects and equivalent sampling depths within each lake; however, depth vs benthos biomass curves constructed for the 19 lakes exhibited congruent patterns to curves reported in the literature (e.g. Brinkhurst 1974).

Two reduced effort models were developed on the premise of sampling only representative zones in each lake and the biomass estimates derived were compared with those of the original intensive sampling design. Model A, which sampled 3 zones per lake, reduced the sampling effort by 56.5% and yielded a correlation coefficient of .92 between biomass estimates when tested against the original design. Model B, which sampled 2 zones per lake, reduced the sampling effort by 66.5% and yielded a correlation coefficient of .88.

Chironomids comprised the largest percentage by number of benthic organisms in all but 4 of the 19 lakes. The abundance of chironomids was found to be highly correlated with total biomass, suggesting that this taxa alone could be used for a quantitative comparison of the benthic community of similar lakes.

Individual curves relating wet weight to length were fitted for 12 selected taxa.

Keywords: Northwestern Ontario, benthic biomass, transects, depth, reduced effort models, biomass curves, chironomids

STANDING STOCK ESTIMATES OF BENTHIC FAUNA FOR A LAKE SET IN NORTHWESTERN ONTARIO

INTRODUCTION

Inherent problems of standardized experimental design and techniques for sampling have continually plagued investigators of invertebrate benthic organisms over the years. Consequently it is difficult to compare the results of earlier studies with those of more recent ones, or to compare results of contemporaneous studies conducted on different bodies of water. The prime concern of this study was to formulate a logistically practical and economically feasible design with which to obtain standing stock estimates of benthic biomass and numbers from a relatively large set of lakes. Quantitative estimates of this nature may be utilized in the refinement of biological indices or in an attempt to "fine tune" a holistic approach to the estimation of fish production. Preliminary work by Rawson (1942, 1955, 1960) and more recent work by Oglesby (1977), Matuszek (1978), and Hanson and Leggett (1982), has, with a moderate degree of success, demonstrated that benthic standing stocks are correlated with morphometric and chemical parameters and can be related to fish yields in order to refine empirical indices (Ryder et al. 1974).

The benthic sampling program was focused on a set of 122 Precambrian Shield lakes within approximately a 100 km radius of Thunder Bay, Ontario, at an approximate latitude of 48°30'N. The study lakes are moderately small, all less than 1000 ha in area, and exhibit a marked diversity of morphometric, edaphic and biological characteristics. The two objectives of this investigation were: 1) to select a single component or group of components of the benthic community which would be related to the limnological characteristics of a lake on the one hand and to the fish production of that lake on the other hand; and 2) to establish a standard procedure for sampling this benthic component which may then be applied practically to all lakes of the set.

Because the complete set of 122 lakes was impractically large for intensive sampling purposes, a subset of 19 lakes was selected to represent both diverse limnological conditions and logistic convenience (Table 1). These lakes ranged in area from 19 to 953 ha and from 1.2 to 8.9 m mean depth, and were considered representative of the entire lake set. A non-random sampling design was applied to the 19 lakes, with the objective of determining the depth variability in the distribution of benthos. This information is prerequisite to the establishment of a standardized sampling procedure which would allow the collection of comparative standing stock data for the entire lake set.

METHODS

SAMPLING DESIGN

A form of systematic non-random sampling was adopted over a random design on the premise that large numbers of samples could be collected in the field with minimal effort and the data could be stratified on a depth basis. A comparative biomass index of the benthos was desired rather than a detailed description of the number and distribution of individual taxa present in each system. Furthermore, prior knowledge of bottom substrates was not adequate to allow for random sampling by depth over similar homogeneous zones within each study lake. Biomass estimates must be representative of the total lake basin, thereby taking into account the major environmental factors which influence contagious or aggregated benthic distribution. In addition, standing stock estimates of the entire lake basin as opposed to estimates derived from station specific or non-specific investigations, increase the versatility of the data, allowing for between lake and within lake partitioning of the data by edaphic and morphometric parameters.

Transects for benthic studies were run from a randomly selected shoreline origin towards the deepest point of the closest major lake depression. The number of transects per lake was subjectively determined in accordance with lake area and basin complexity. However, because the range of lake areas varied across 4 orders of magnitude, it was rationalized that benthic sampling intensity should not be linearly related to lake area. Accordingly, a formula was devised to determine the number of transects required, based on the logarithm of lake area multiplied by the shoreline development factor (Table 2). Three transects per lake, each spanning all depth strata from 1 m to maximum depth, were chosen as a minimum required intensity of sampling that might produce reliable comparative data from even the largest lakes in the set.

Sampling stations along the transects were standardized at depths of 1, 2, 3, 5, 7, 10, 15 and 20 m and at maximum depth. Single samples were collected for each station in accordance with the concept that multiple sampling at a single station for whole lake investigations may be redundant, that is, for a fixed number of samples, the greatest amount of precision can be obtained by having a single sample per station, thereby allowing more effort at different stations (Cuff and Coleman 1979).

According to this sampling regime, too many samples were required for practical purposes within a restricted field season. Consequently, the number of samples was reduced as lake depth increased, since, in general, the diversity of benthic organisms decreases with depth which corresponds to the generally

increased homogeneity of habitat. In addition, the total area of habitat in most instances decreased beyond a critical depth. Hence, the number of individual samples was systematically reduced by the deletion of stations beyond the critical depth while always maintaining a minimum of 3 samples per depth stratum.

The first 3 transects included stations at all standardized depths of 1 m to maximum depth. A maximum of 5 stations at depths 1 through 7 m were sampled along transect No. 4, followed by a systematic reduction of the deepest station for each successive transect. Sampling frequency along transect No. 4 in lakes with a maximum depth of 7 m or less was equal to the sampling frequency of transect No. 3 minus the deepest station, followed by a reduction of the deepest station for each successive transect.

Seasonal variation of benthic biomass is a problem that can be minimized by restricting sampling to the shortest time period possible. Seasons of maximum population fluctuations such as late summer and autumn (early instars) and spring (final instars) which are characterized by stanzas of maximum growth and emergences in some organisms, should be avoided. Oliver (1960) found minimum variation in specific chironomid abundance over a range of depths during the period late June through mid-August. Preliminary investigations indicated chironomids were the dominant taxa in terms of both biomass and numbers in the study lakes. Hence, benthos sampling was conducted from July 6, 1979 to September 6, 1979 which coincided favourably with ongoing limnological data collection. Increased predation on shallow-water fauna (Gerking 1962) and post emergence lows of benthos with an aerial phase in their life history (Ball and Hayne 1952), may result in a summer minimum in standing stocks of benthos. Ultimately low biomass estimates however, can be analyzed on a comparative basis, both within and between lakes and with a thorough knowledge of seasonal fluctuations within major taxonomic groups, biomass estimates could be adjusted accordingly.

GEAR

There are limitations to single gear studies which are directly related to the physical characteristics of the substrate, the types of organisms present and the objectives of the experimental design. However, within the context of a large number of lakes and a short sampling season, it was undesirable to use a variety of sampling gear to obtain absolute estimates of biomass. The Ponar grab sampler was considered to be a suitable compromise in order to determine an optimum estimate of community structure and biomass.

Precision of benthic estimates is dependent on sample density, sample size and number of samples taken (Cochrane 1977). Considering that increased precision can be achieved by increasing sampling frequency with a small sampler and that the amount of work necessary to process samples increases significantly with a large sampling device (Downing 1979), the 232 cm^2 "petit" model of Ponar was chosen. Although dredges of most designs create sampling problems in specific substrates (Resh 1979), the versatile Ponar has been demonstrated to be a most efficient general sampling device when operated over a variety of bottom types from ooze to sand (Flannagan 1970; Hudson 1970).

Deviations from the sampling model occurred only when a bedrock or boulder type substrate was encountered. The Ponar, as characteristic of most dredges, was ineffective in collecting a sample at these locations; therefore, the station was recorded as unsampled and was not included in mean calculations at that particular stratum or transect. The total allotment of stations on the study lakes was 403 of which 43 were subsequently excluded due to the inability of the Ponar dredge to penetrate the substrate adequately.

By excluding "no samples" from data analyses we are forced to make the improbable assumption that rocky substrates support similar contagious benthic distributions as other substrate types in each depth stratum. Alternate or supplementary sampling techniques, possibly in the form of natural substrate (Kajak 1964), suction (Gale and Thompson 1975), or light trap sampling (Faber 1981), may be required to resolve this discrepancy. Light traps may be the most applicable of the 3 methods pertaining to effort required and sampling the profundal zone while also reducing the effects of contagious distributions because of the extensive area represented by each sample.

SORTING AND ANALYSIS OF SAMPLES

Initially, all samples were immediately passed through a wash frame for removal of bulk debris. The wash frame was designed after the Wildco Model No. 188 with dimensions (10.6 cm x 50.8 cm x 35.6 cm). Lightweight, buoyant redwood was used in construction of the frame rather than a brass frame to allow greater ease of screening while operating in less than ideal field conditions. All specimens and particles larger than 500 μ were retained on the No. 32 brass screen after the initial washing. Each sample was then preserved in a 10% formalin solution for transport to the laboratory.

The sugar flotation technique (Anderson 1959) proved to be the most efficient and least expensive method of separating the benthos from the remaining sediment. Flotation time of organisms varies with the type of preservative used (Howmiller 1972). However, this time period is optimized by floating specimens live, or following preservation in formalin solution (Anderson 1959).

A maximum flotation period of 5 minutes was set for each sample in a sugar solution of 1.12 specific gravity. The sediment was agitated through this period with air bubbles injected into the bottom of the container. Generally, one flotation was sufficient in collecting the benthos from the sample with the exception of samples containing exceedingly high numbers of specimens and large quantities of organic debris. Manual searching of the sediment for mollusks and other non-floating specimens was necessary after each flotation.

Identification was made to order or family, and length measurements were recorded for each specimen by use of a stereo microscope fitted with an ocular scale divided in 100 units of 0.167 mm. Length measurements were recorded as the maximum distance along the longitudinal axis of the organisms, excluding appendages. Measurement intervals were set at .835 mm with a minimum body measurement of 1.67 to 5.01 depending on the characteristic spherical to longitudinal shape of each taxon.

Wet weight values for whole samples and representative specimens were recorded on an analytical balance accurate to .1 mg. Prior to weighing, a filtration unit powered by a vacuum pump was used to subject each sample to a constant flow of air for approximately one minute, resulting in the removal of excess moisture.

STATISTICAL ANALYSIS

Standing stock estimates in terms of biomass (wet weight) and numbers were calculated for each lake on a depth basis. The means of all samples collected at each depth interval were weighted in proportion to the actual area of substrate each particular depth stratum encompassed.

A within lake, one-way analysis of variance was performed on the data as a preliminary statistical investigation of standing stock patterns. Biomass (wet weight) was classified as the dependent variable in all cases with transect and depth classed as the independent variable. Only transects covering similar depths and therefore composed of the same number of sample sites were included in this analysis.

Regression analyses were employed in order to determine: 1) the relations between biomass estimates produced by the reduced effort models and those of the original design; 2) the relations between the number of chironomids per Ponar grab and total benthic biomass; and 3) the relations between individual body length and wet weight for selected taxa.

RESULTS

Standing stock estimates based on wet weight ranged from a low of 11.0 kg ha^{-1} in Trout Lake to a high of 60.5 kg ha^{-1} in Inwood Lake. Total numbers of organisms ha^{-1} ranged from 3.0×10^6 in Unnamed #24 Lake to 21.5×10^6 in Inwood Lake (Table 3).

An analysis of variance comparing benthic biomass means at different depths revealed differences at the 5% level of significance in only one case. This result was explained by the high degree of variation that occurred between Ponar grabs. In most cases, there was greater variation in biomass among samples collected at each depth than occurred among sample means at different depths. This is clearly shown by depth vs biomass curves of the 19 lakes (Fig. 1).

To fulfill the objective of establishing a standard procedure for sampling the benthic component which could be practically applied to all lakes of the set, a further reduction of effort from the original model was required. In light of the great variability among samples, reducing the number of transects, or number of stations per depth strata appeared to be undesirable if truly representative benthic estimates were to be obtained. However, as biomass patterns appear well defined within certain depth zones, sampling within these zones only would be an acceptable alternative. This approach would maintain the same number of transects and stations per depth as in the original survey, but would lessen the sampling effort significantly by reducing the number of depth strata where sampling was required.

As benthic species concentrate in the profundal and littoral zone and exhibit low densities between these regimes, representative sampling from each of these 3 zones should yield a realistic overall profile of total lake benthos. The specific depth at which to sample within these well defined regions was established, through correlation analysis, to be 1 m for the littoral zone, mid-thermocline depth for the transitional zone, and maximum lake depth for the profundal zone. Unstratified lakes would be sampled only at the 1 m strata and maximum depth.

Estimated benthic biomass and abundance calculated by pooling samples collected only at these 3 depths (Model A), when regressed against those for the original design, yielded correlation coefficients of .92 and .94, respectively, and represented a reduction in sampling effort of 56.5% (Fig. 2).

An even greater reduction in effort (66.5%) could be achieved by deleting mid-thermocline depth samples from thermally stratified lakes (Model B). Correlation coefficients of .88 resulted from regressing biomass and numbers estimated from the original design against reduced effort Model B (Fig. 3).

Chironomids comprised the largest percentage by number of benthic organisms in all but 4 of the 19 lakes (Table 4). They exhibited a frequency of occurrence of 18% to 77% by total numbers for all the major taxonomic groups. Numbers of chironomids per Ponar grab when regressed against total benthic biomass yielded a highly significant correlation (r = .78), emphasizing a general chironomid dominance in the benthic community structure. Inwood Lake could be considered an outlier in the above regression analysis considering the average number of chironomids was 34 organisms per sample as compared to the next highest density, 15 organisms per sample found in Iron Range Lake. Excluding Inwood Lake from the above regression analysis increased the correlation to r = .88 (Fig. 4). Inflated chironomid densities occurring in this lake may be partially explained by the absence of white sucker, *Catostomus commersoni*, a major benthic predator (Beamish 1974), that was present in all other study lakes having a maximum depth of greater than 1.5 m.

Individual weight and length measurements of representative organisms for each of 13 selected taxa yielded correlation coefficients ranging from .90 to .99, significant at the 1% level (Table 5). Great differences in total length between specimens of otherwise similar size occurred in the two family groups, Hirudinea and Oligochaeta, apparently due to extreme morphological variation and longitudinal shrinkage caused by the preservative. Consequently, surface area replaced length measurements for these groups, which yielded correlation coefficients of .98 when regressed against weight.

DISCUSSION

The depth vs biomass curves (Fig. 3) exhibit a general pattern of decreasing benthic variability and biomass with depth similar to those reported in the classical benthos studies of Deevey (1941) and Brinkhurst (1974). Theoretically, under mesotrophic and eutrophic conditions, a biomodal pattern of biomass becomes evident in depth distribution curves (Fig. 1-M). The 2 peaks are composed for the most part, of littoral and profundal species separated by a trough of low density caused by a transition zone of rapid chemical and temporal change (Brinkhurst 1974). Comparatively high biomass concentrations and variability occurred in the littoral zone defined as that portion of a lake with a water depth less than 5 m. The exception of Trout, Madalaine and Sunbow Lakes (Fig. 1-D, K, Q) may be attributed to the predominance of unproductive sand substrates in this zone within these lakes. The great variation in biomass between samples collected in the littoral zone is probably the result of habitat heterogeneity and food availability. Wave action may result in a slight drop in the quantity of near-shore littoral benthos (Brinkhurst 1974); however, due to the small size and irregular morphometry of the study lakes, resultant short wind fetches likely would have a minimal effect on benthic quantity. The second peak in biomass occurring in the upper profundal zone may be explained by optimal and relatively stable environmental conditions. Less productive oligotrophic lakes, on the other hand, do not exhibit this concentration of organisms as a result of lower levels of phytoplankton production (Fig. 1-P).

The transition zone of low benthic density in deeper stratified lakes occurred at the metalimnetic depth during mid-summer stratification. Shallow, unstratified lakes, with a maximum depth of 6 m or less (Fig. 1-A, G), are comprised almost entirely of littoral zone and thus lack this transitional region of lower densities.

The highly significant correlation coefficients resulting from the regression of biomass or number of benthic organisms estimated from the original design against the corresponding estimates from the reduced effort Models A and B (Figs. 2 and 3), suggests representative subsampling of organisms adapted to the littoral, transitional and profundal zones did occur with the latter models. Consequently, lake-wide standing stock extremes, spanning zones of greatest diversity in the littoral, to that of relatively homogeneous conditions in the profundal, are subsumed under a depth stratified estimate of this nature. Sampling effort reductions from the original model of 56.5% for Model A and 66.5% for Model B would make sampling of a larger set of lakes much more practical.

Chironomid dominance by biomass and numbers within the benthic community is highly evident (Table 4). The chironomid population may be highly representative of the total benthic community in terms of energy availability and energy transfer to higher trophic levels. An organism of this nature may have utility with respect to predictive and comparative analysis when benthic studies are extended over a large number of lakes, with geographic and temporal variation minimized.

As illustrated in Fig. 4, a simple enumeration of chironomids within a benthic sample will yield a first approximation biomass estimate of benthos for a particular lake. Such an approach would require much less time and technical expertise than the traditional laboratory analysis of sorted benthic samples.

Construction of weight-length curves for benthic organisms may offer more precise estimates of biomass, depending on the taxonomic level investigated. Curves of this nature can have significant predictive and time-saving properties, when dealing with organisms subjected to similar factors governing growth such as temperature and food availability. Basic weight-length relationships have limited usefulness as accuracy requirements of a given model increase; however, on a comparative basis, and with limited effort, biomass patterns may be identified, especially when large data sets are available. Computerized calculations of equivalent spherical diameters (Schwinghamer 1981) using weight-length predictive equations would provide a simplified method of mapping the size spectrum of benthic communities for the purpose of applying the particle size theory (Sheldon et al. 1972) in community structure and productivity studies.

Errors resulting from removal of excess external moisture prior to weighing may be exaggerated as specimen size decreases. Wet weights, therefore, should form the basis of initial data investigations, followed by a more insightful approach based on dry weight values. Dry weights are a highly preferred weight measurement, yielding precise data for analysis and a basis for meaningful between-study comparisons when standardized procedures are adopted (Lovegrove 1966).

Length of preservation, type of preservative and specific organisms preserved can affect biomass estimates of marine and freshwater benthos (Howmiller 1972; Mills et al. 1982). The degree of weight loss that preservatives will cause is directly dependent on these 3 factors at a proportionately higher level during the initial period of preservation. Mills et al. (1982) suggested that weights should not be recorded for at least one month after preservation, at which time weight loss over time tends to level off. Furthermore, organisms preserved in a 10% formalin solution tend to incur the least weight loss compared to organisms preserved in ethanol and isopropanol.

Weights obtained from preserved specimens, subjected to similar preparatory procedures, will yield acceptable biomass estimates for within-study comparative analysis. Discrepancies occur however, when comparisons are drawn between results of studies in which preparatory methods differed.

ACKNOWLEDGEMENTS

Special thanks are extended to Peter Waring, Regional Fisheries Biologist, Ministry of Natural Resources, for initiating this study and for helpful suggestions during the analysis. I am indebted to Dick Ryder, Research Scientist, and Terry Marshall, Research Biologist, for providing assistance and direction during all aspects of this study and specifically the manuscript preparation. This program was supported by the Productivity Research Unit of the Ministry of Natural Resources.

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Table 1. Morphometric data for selected lakes in the Thunder Bay District.

Lake	Area (ha)	Mean depth (m)	Volume ($10^4 m^3$)	Maximum depth (m)	Shoreline (km)	Shoreline development factor (DL)[a]	Percent littoral zone[b]
Howcum	10.1	3.3	33.7	11.5	1.77	1.57	74.9
Inwood	12.2	2.9	35.5	6.1	1.51	1.96	81.3
Iron Range	203.5	3.2	650.5	5.8	9.66	.91	81.1
Lottit	51.4	1.7	86.1	8.2	7.55	.97	96.9
Madalaine	125.7	2.7	344.6	6.0	6.94	1.75	96.8
Missing	19.1	1.5	29.2	3.0	2.05	1.32	100.0
Paul #1	20.1	4.2	84.5	10.8	2.69	1.69	64.8
Pesheau	63.8	1.5	96.5	3.8	8.35	2.95	100.0
Prelate	143.6	3.7	527.7	12.5	10.87	2.56	67.8
Reta	118.0	3.3	392.7	13.9	9.76	2.53	83.6
Roundtable	113.2	3.7	423.1	15.3	5.84	1.55	81.9
Sandstone	953.5	8.9	8505.1	23.9	24.55	2.24	35.4
Sunbow	656.5	6.4	4173.5	22.2	30.19	3.32	42.9
Timmus	25.6	7.7	196.7	24.1	2.21	1.23	49.1
Trout	84.6	3.1	264.0	5.5	4.76	1.46	95.9
Unnamed #22	28.0	1.2	33.7	1.3	1.88	1.00	100.0
Unnamed #23	19.4	3.5	67.6	5.9	2.36	1.51	70.6
Unnamed #24	22.7	4.1	93.2	9.5	3.09	1.83	63.2
Whitelily	42.1	1.8	75.8	4.6	4.56	1.98	100.0

[a] The ratio of the length of the shoreline to the length of the circumference of a circle of area equal to that of the lake: $DL = L/2\sqrt{\pi A}$.
[b] Area of lake with <5.0 m water depth as a percentage of the total area.

Table 2. Logarithmic transect scale for determining number of sampling transects per lake.

Scale $Log_{10}(AreaxDL)$[a]	Minimum number of transects
1.5 or less	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8

[a] DL = Shoreline Development Factor

Table 3. Summary of the biomasses and number of benthic organisms in the 19 study lakes.

Lake	Total area (ha)	Samples per lake (n)	Total wet weight (kg ha^{-1})[a]	Total numbers (org ha^{-1} x 10^6)
Howcum	10.1	18	21.0	15.1
Inwood	12.2	17	60.5	21.5
Iron Range	203.5	15	56.7	8.0
Lottit	51.4	20	30.2	8.2
Madalaine	125.7	20	25.8	7.4
Missing	19.1	7	37.8	8.2
Paul	20.1	20	30.3	6.9
Pesheau	63.8	10	15.9	3.2
Prelate	143.6	29	37.4	7.3
Reta	118.0	23	17.7	5.0
Roundtable	113.2	25	26.4	11.1
Sandstone	953.5	39	14.8	8.1
Sunbow	656.5	29	26.8	6.8
Timmus	25.6	24	29.5	5.6
Trout	84.6	15	11.0	3.9
Unnamed #22	28.0	5	41.2	13.9
Unnamed #23	19.4	12	22.7	7.3
Unnamed #24	22.7	19	16.4	3.0
Whitelily	42.1	13	53.7	10.5

[a] Mollusk shells excluded.

Table 4. Taxonomic breakdown by lake in terms of absolute numbers in pooled samples and their percentage of the total.

	Howcum		Inwood		Iron Range		Lottit		Madalaine		Missing		Paul	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
PELECYPODA							1	.2						
Sphaeriidae	10	3.4	46	5.5	72	11.4	4	1.0	11	3.4	1	.8	4	1.3
GASTROPODA					81	12.8	4	1.0			3	2.5	3	1.0
Planorbidae			2	.2	2	.3	1	.2					2	.7
DIPTERA														
Chironomidae*	98	32.9	640	77.2	242	38.0	132	31.6	134	41.0	43	35.2	141	46.8
Chaoborinae*	148	49.7	58	6.8	51	8.0	184	44.0	36	11.0	17	13.9	58	19.3
Heleidae*	11	3.7	48	5.8	12	1.9	19	4.5	23	7.0	6	4.9	17	5.6
Tabanidae*														
Simuliidae*														
Diptera Pupa	1	.3	4	.5	10	1.6	2	.5	28	8.6	4	3.3	3	1.0
COLEOPTERA	2	.7			3	.5			5	1.5				
Elmidae*					1	.2							3	1.0
Halipidae*														
Dryopidae*														
TRICHOPTERA*	10	3.4	12	1.4	17	2.7	14	3.3	2	.6	1	.8	8	2.7
MEGALOPTERA														
Sialidae*			2	.2	7	1.1			1	.3			3	1.0
Corydalidae*														
HEMIPTERA														
Corixidae													3	1.0
ODONATA														
Anisoptera*			4	.5	14	2.2	2	.5					4	1.3
Zysoptera*														
EPHEMEROPTERA	18	6.0	7	.8	58	9.1	39	9.3	24	7.3	5	4.1	21	7.0
HYDRACARINA					2	.2								
DECAPODA									1	.3				
AMPHIPODA					36	5.7	1	.2	12	3.7	40	32.8	10	3.3
ANNELIDA														
Oligochaeta			5	.6	25	4.0	12	2.9	45	13.8	2	1.6	18	6.0
Hirudinea					3	.5			1	.3				
NEMATODA			1	.1	1	.2	3	.7					3	1.0
	298		829		637		418		327		122		301	

Table 4 continued on page 9.

*Larvae

Table 4. Taxonomic breakdown by lake in terms of absolute numbers in pooled samples and their percentage of the total (continued).

	Pesheau		Prelate		Reta		Round-table		Sand-stone		Sunbow		Timmus	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
PELECYPODA			1	.2										
Sphaeriidae	2	2.9	18	4.0	30	10.1	37	6.0	29	3.7	19	3.7	17	5.5
GASTROPODA	4	5.8	11	2.4	6	2.0	40	6.5	27	3.5	3	.6	3	1.0
Planorbidae					6	2.0	10	1.6	7	.9	2	.4		
DIPTERA														
Chironomidae*	37	53.6	190	42.0	78	26.3	186	29.9	188	24.2	186	36.5	205	66.6
Chaoborinae*	4	5.8	48	10.6	72	24.2	131	21.2	58	7.5	25	4.9	25	8.1
Heleidae*			18	4.0	9	3.0	9	1.5	39	5.0	9	1.8	7	2.3
Tabanidae*														
Simuliidae*									2	.3				
Diptera Pupa	1	1.4	14	3.1	6	2.0	49	7.9	31	4.0	1	.2	1	.3
COLEOPTERA														
Elmidae*					5	1.7	4	.6	34	4.4	156	30.7	2	.7
Halipidae*														
Dryopidae*											1	.2		
TRICHOPTERA*	2	2.9	4	.9	4	1.7	7	1.1	2	.3	2	.4	5	1.6
MEGALOPTERA														
Sialidae*			8	1.8	4	1.3	4	.6	2	.3	4	.8	1	.3
Corydalidae*														
HEMIPTERA														
Corizidae														
ODONATA														
Anisoptera*			3	.7	2	.7							4	1.3
Zysoptera*							1	.2	2	.3	1	.2		
EPHEMEROPTERA*	2	2.9	46	10.2	50	16.8	14	2.3	51	6.6	21	4.1	30	9.7
HYDRACARINA					1	.3			1	.1	2	.4		
DECAPODA														
AMPHIPODA	1	1.4	54	11.9	9	3.0	94	15.2	174	22.4	21	4.1		
ANNELIDA														
Oligochaeta	15	21.7	33	7.3	10	3.4	28	4.7	83	10.7	42	8.3	5	1.6
Hirudinea			1	.2	2	.7	1	.2	37	4.8	9	1.8		
NEMATODA	1	1.4	4	.9	2	.6	3	.5	7	.9	5	1.0	3	1.0
	69		452		297		618		774		509		308	

Table 4 continued on page 10.

*Larvae

Table 4. Taxonomic breakdown by lake in terms of absolute numbers in pooled samples and their percentage of the total (continued).

	Trout		Unnamed #22		Unnamed #23		Unnamed #24		Whitelily	
	#	%	#	%	#	%	#	%	#	%
PELECYPODA										
Sphaeriidae	2	1.8	5	3.1	2	.9	3	2.0	2	.8
GASTROPODA	1	.9	4	2.5	1	.5	1	.7	3	1.2
Planorbidae			2	1.2			1	.7	3	1.2
DIPTERA										
Chironomidae*	34	31.2	30	18.6	65	30.7	67	45.0	137	53.7
Chaoborinae*	47	43.1			52	24.5			47	18.4
Heleidae*	6	5.5	19	11.8	10	4.7	18	12.1	7	2.7
Tabanidae*							1	.7		
Simuliidae*										
Diptera Pupa	4	3.7					10	6.7	1	.4
COLEOPTERA										
Elmidae*	1	.9					4	2.7	6	2.4
Halipidae*										
Dryopidae*										
TRICHOPTERA*	2	1.8			6	2.8			5	2.0
MEGALOPTERA										
Sialidae*	1	.9							9	3.5
Corydalidae*							1	.7		
HEMIPTERA										
Corixidae	3	2.8	1	.6	1	.5				
ODONATA										
Anisoptera*	1	.9					1	.7		
Zysoptera*										
EPHEMEROPTERA*	4	3.7			14	6.6	11	7.4	11	4.3
HYDRACARINA										
DECAPODA										
AMPHIPODA			94	58.4	40	18.9	7	4.7	10	3.9
ANNELIDA										
Oligochaeta	3	2.8	1	.6	12	5.7	24	16.1		
Hirudinea			5	3.1	9	4.2			5	2.0
NEMATODA									10	3.9
	109		161		212		149		255	

*Larvae

Table 5. Regression constants with 95% confidence intervals, required to predict wet weight (mg) from length measurements (mm) of selected benthic taxa. Length was measured along the longitudinal axis, excluding appendages, of each organism, unless otherwise noted. Equation form: Log W = Log a + b Log L where W = weight, L = length, a = intercept and b = slope.

Taxon	n[a]	Regression constants		
		log a	b	r[c]
Anisoptera	15	-1.65 ± .33	3.08 ± .28	.99
Chironomidae	47	-2.28 ± .39	2.70 ± .33	.95
Chaoborinae	27	-2.09 ± .65	2.58 ± .60	.92
Diptera Pupa	20	-2.19 ± .43	3.30 ± .55	.95
Elmidae	26	-2.16 ± .65	2.39 ± .90	.96
Ephemeroptera	39	-1.89 ± .19	2.74 ± .17	.98
Gastropoda	11	-0.65 ± .86	2.54 ± 1.57	.98
Heleidae[b]	16	-3.21 ± .31	3.16 ± .30	.99
Hirudinea[b]	22	-0.55 ± .14	1.28 ± .13	.98
Oligochaeta[b]	27	-0.58 ± .09	1.26 ± .10	.98
Planorbidae	12	-0.73 ± .30	2.43 ± .67	.93
Trichoptera	22	-1.70 ± .53	2.55 ± .74	.90
Sialidae	18	-2.17 ± .41	3.06 ± .42	.97
Sphaeriidae	24	-0.68 ± .31	2.59 ± .52	.95
Talitridae	23	-1.42 ± .52	3.14 ± .91	.94

[a] Actual number of organisms included in wet weight measurement.
[b] Regressions of wet weight (mg) and surface area (mm^2).
[c] $P \leq 0.01$.

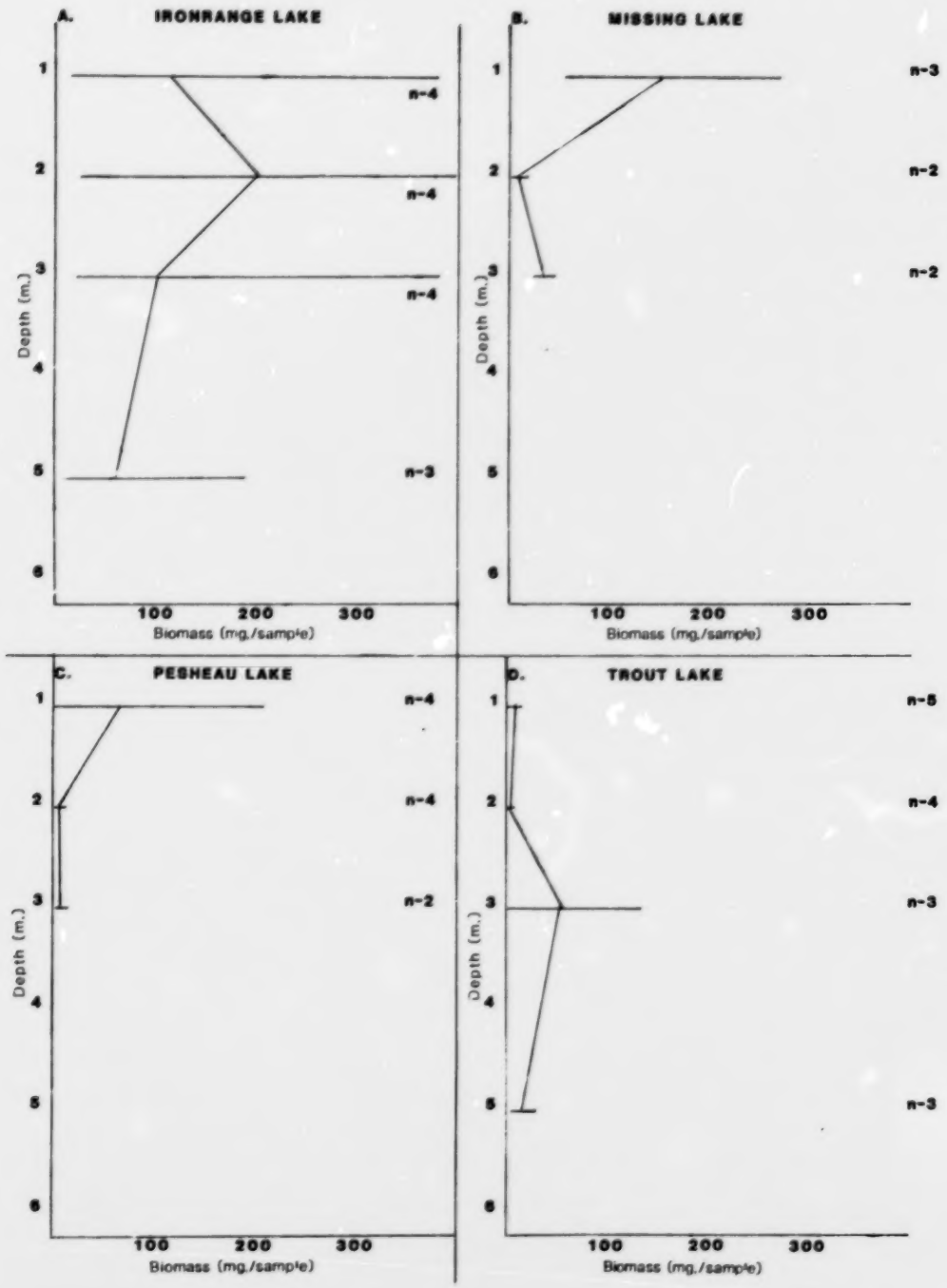

Fig. 1. Benthos vs depth biomass curves for 19 lakes. N represents the number of samples, while the horizontal bars indicate the range in sample biomass at each depth.

Fig. 1 continued on page 13.

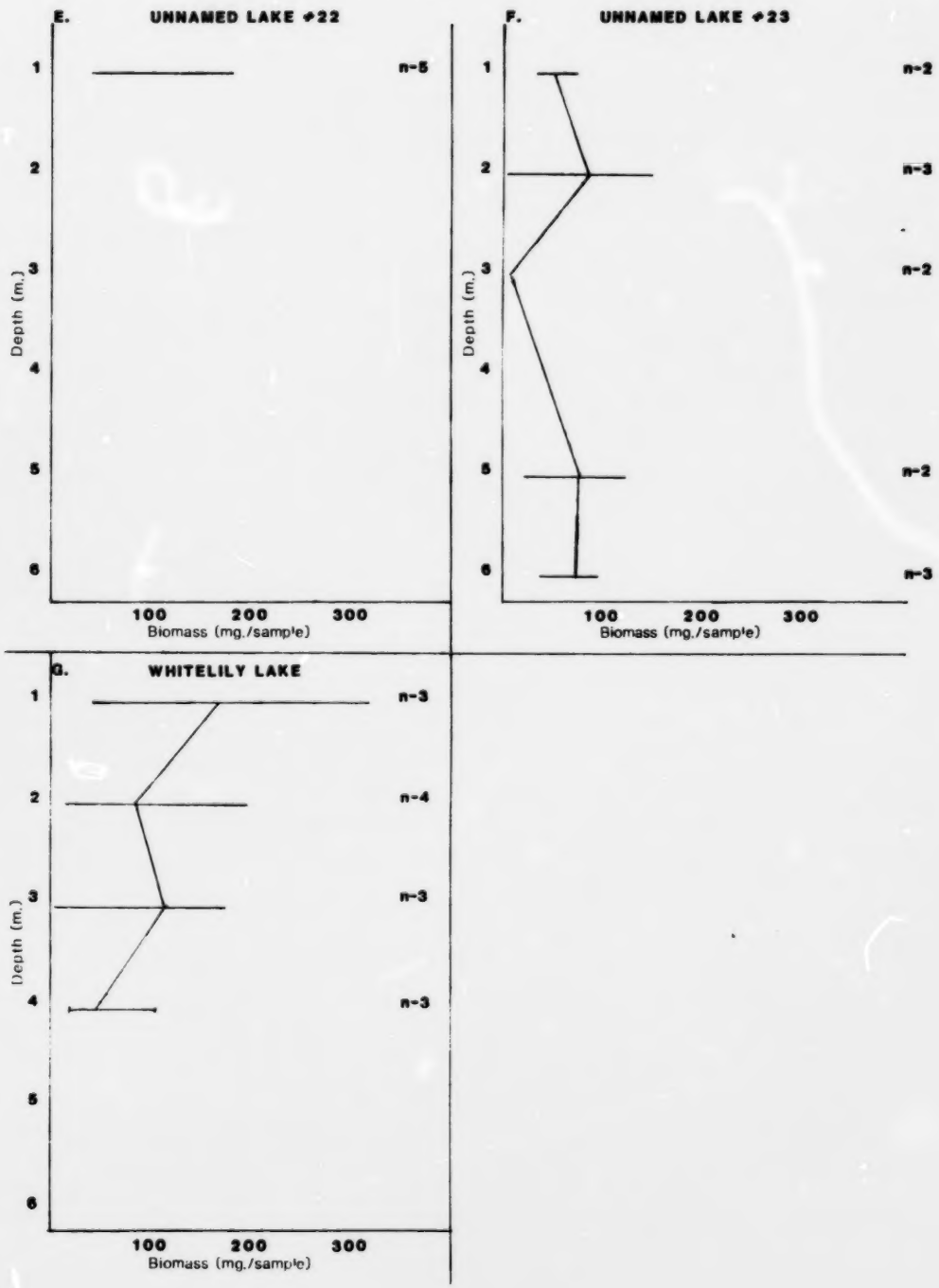

Fig. 1. Benthos vs depth biomass curves for 19 lakes. N represents the number of samples, while the horizontal bars indicate the range in sample biomass at each depth (continued).

Fig. 1 continued on page 14.

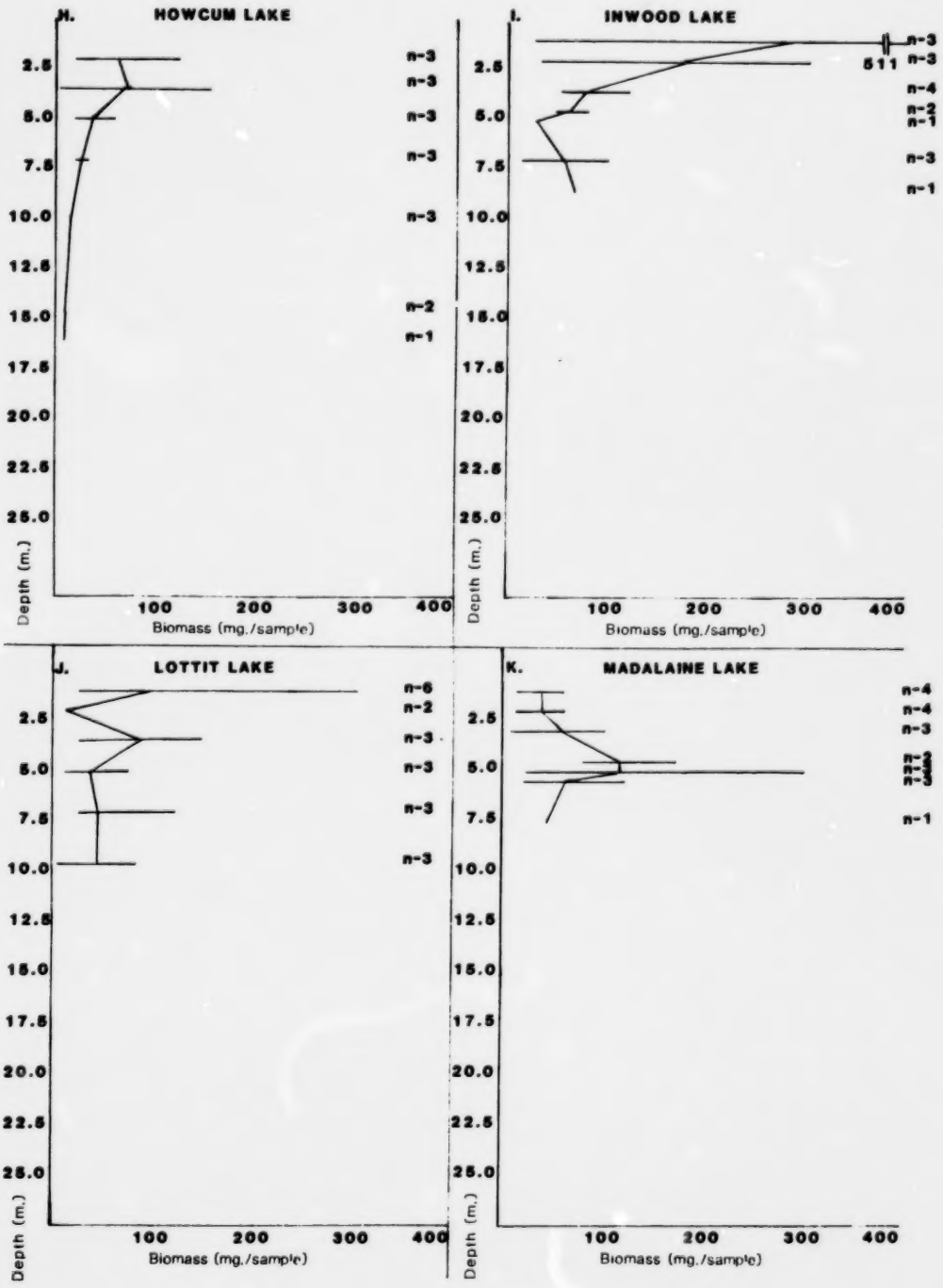

Fig. 1. Benthos vs depth biomass curves for 19 lakes. N represents the number of samples, while the horizontal bars indicate the range in sample biomass at each depth (continued).

Fig. 1 continued on page 15.

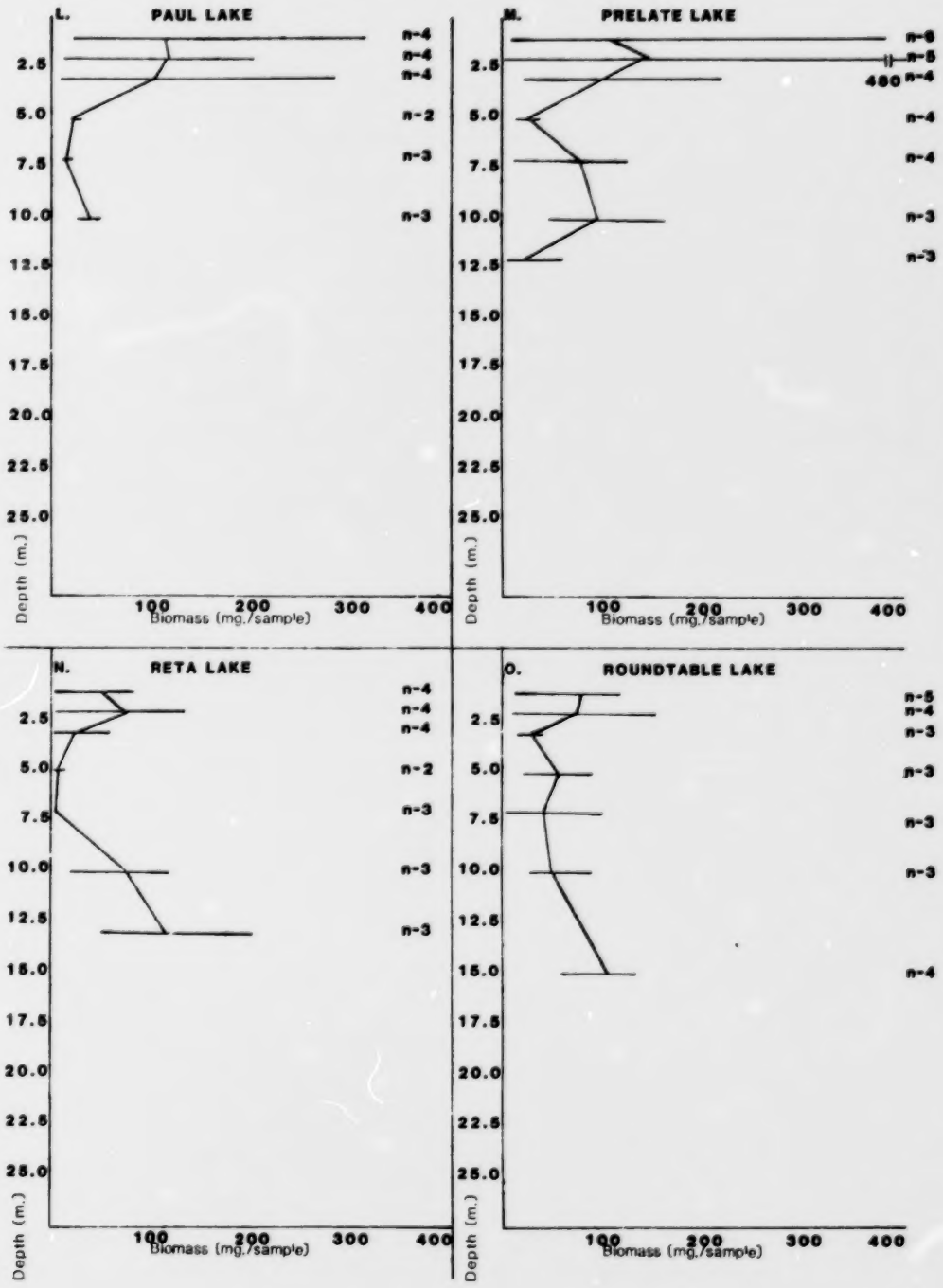

Fig. 1. Benthos vs depth biomass curves for 19 lakes. N represents the number of samples, while the horizontal bars indicate the range in sample biomass at each depth (continued).

Fig. 1 continued on page 16.

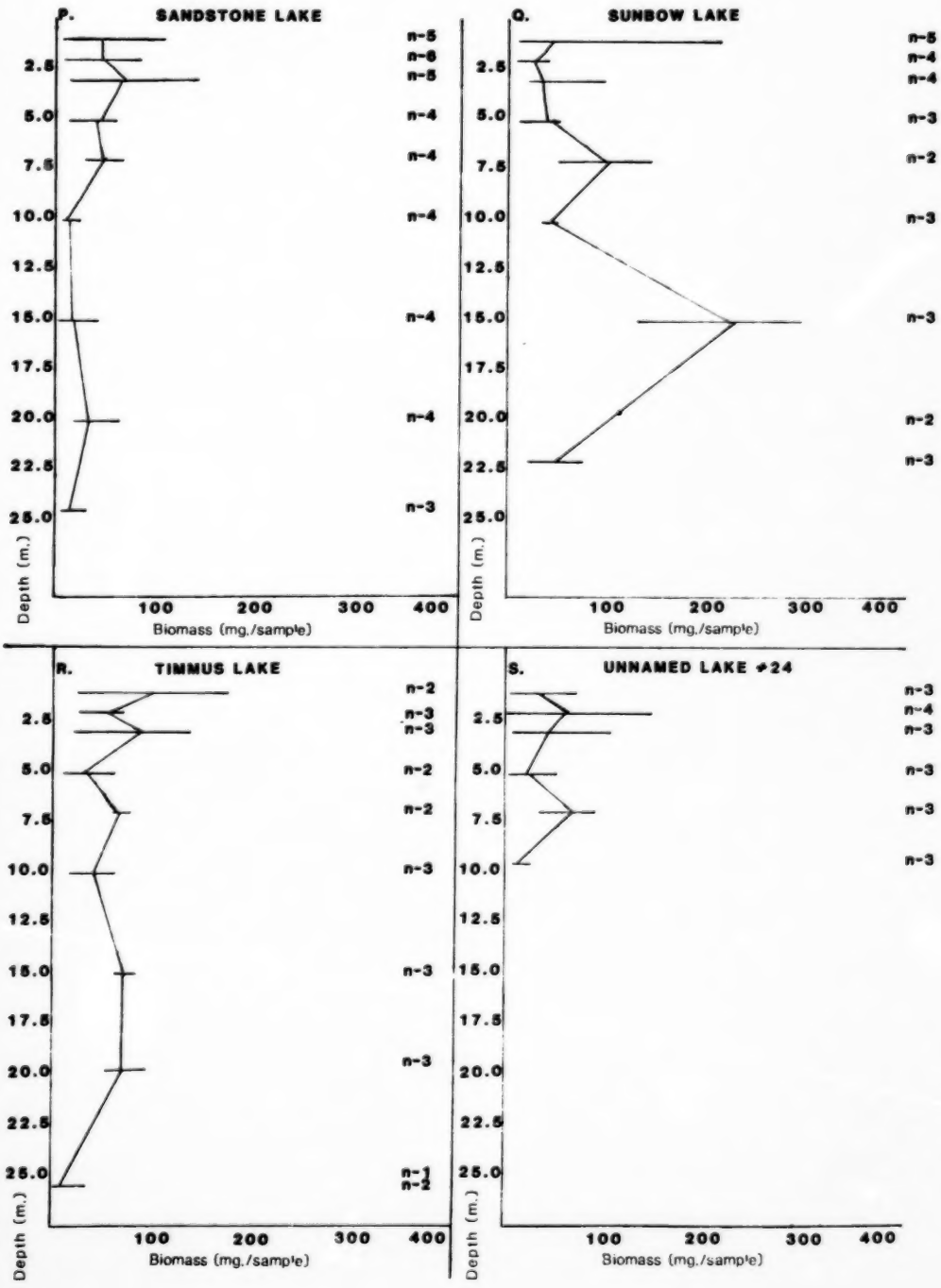

Fig. 1. Benthos vs depth biomass curves for 19 lakes. N represents the number of samples, while the horizontal bars indicate the range in sample biomass at each depth (continued).

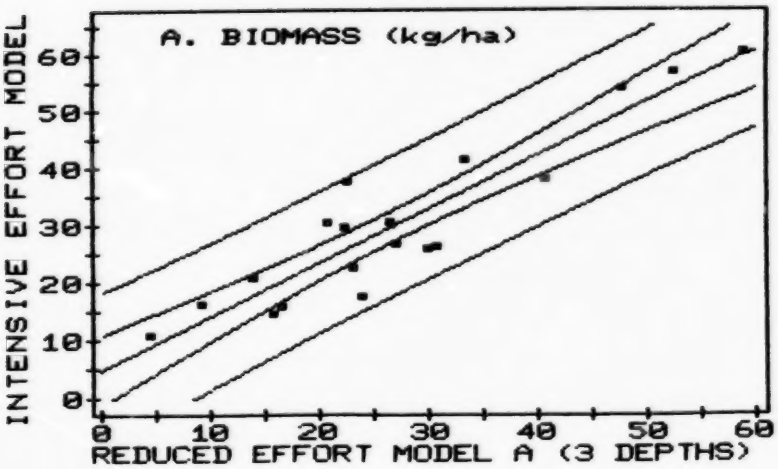

Fig. 2A. Regression of biomass estimated from the original sampling design on that estimated from the reduced effort Model A, with the 95% confidence limits for the sample and mean indicated; intercept = 4.8, slope = .93 and r = .92 for N = 19.

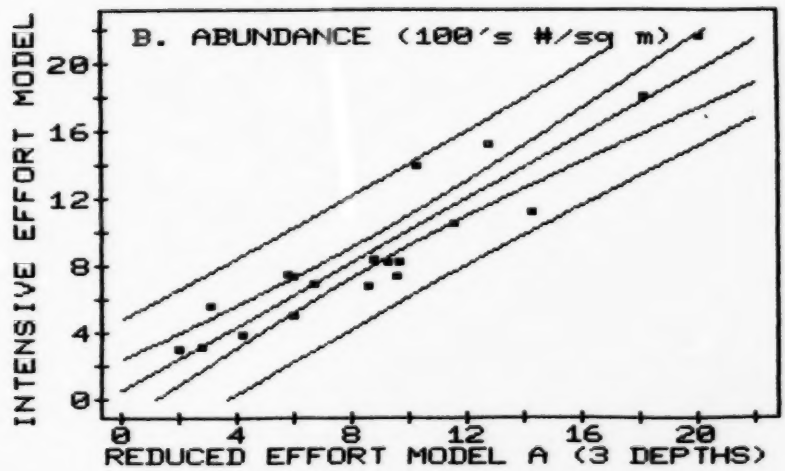

Fig. 2B. Regression of number (abundance) estimated from the original sampling design on that estimated from Model A, with the 95% confidence limits for the sample and mean indicated; intercept = 51.93, slope = .95 and r = .94 for N = 19.

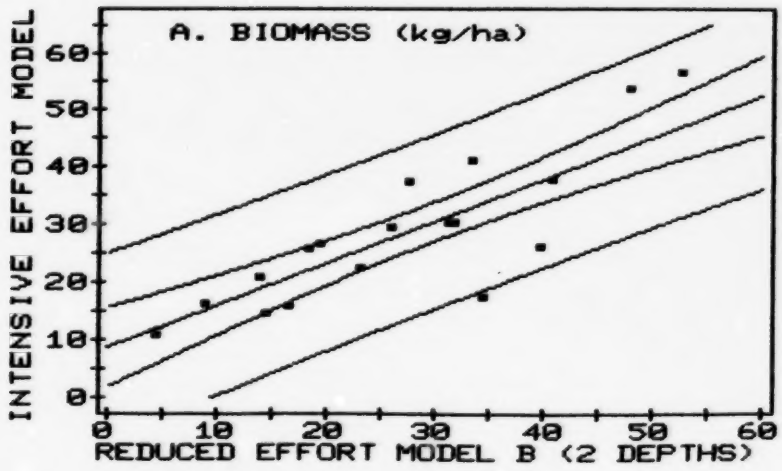

Fig. 3A. Regression of biomass estimated from the original sampling design on that estimated from the reduced effort Model B, with the 95% confidence limits for the sample and mean indicated; intercept = 8.6, slope = .73 and r = .88 for N = 19.

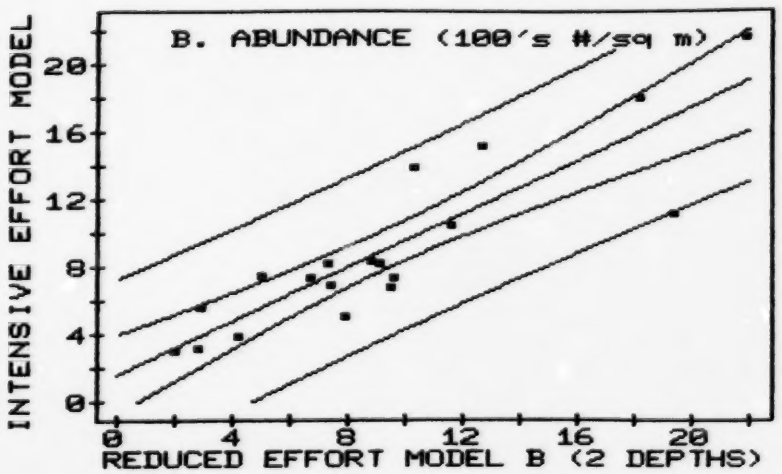

Fig. 3B. Regression of number (abundance) estimated from the original sampling design on that estimated from Model B, with 95% confidence limits for the sample and mean indicated; intercept = 161, slope = .79 and r = .88 for N = 19.

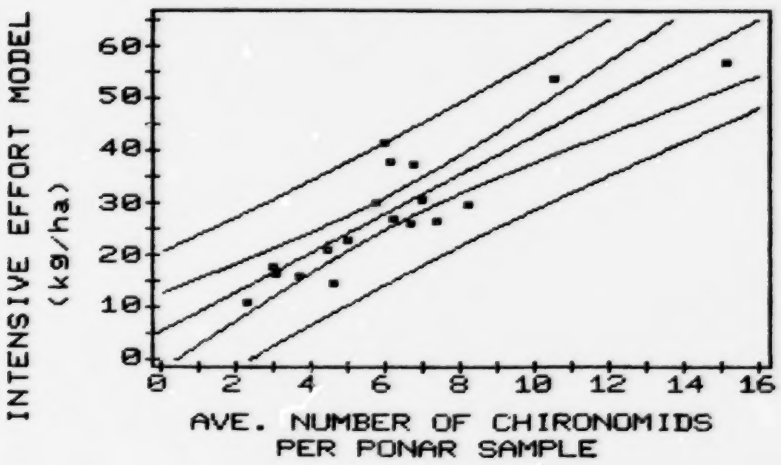

Fig. 4. Relation between total benthic biomass (kg ha^{-1}) and chironomid abundance (mean number per grab sample) with 95% confidence intervals for the sample and the mean; intercept = 5.4, slope = 3.7, r = .88 for N = 18 (Inwood Lake excluded from the analysis).

APPENDIX A. SAMPLING FREQUENCY EXAMPLE.

Lake:	Sandstone	S.D.F.:	2.24
Max. Depth:	24 meters	Log_{10} (Area x SDF):	3.3
Area:	953.6 hectares	No. of transects: (Table 2)	7

Depth (m)	Transects						
	1	2	3	4	5	6	7
1	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x
3	x	x	x	x	x	x	
5	x	x	x	x	x		
7	x	x	x	x			
10	x	x	x				
15	x	x	x				
20	x	x	x				
24	x	x	x				

x = 1 sample, total number of samples for Sandstone Lake equaled 41 samples.

Original Model - Biomass estimate was calculated using data from all 41 proposed samples.

Model A - Biomass estimate was calculated using the 14 samples from the 1, 7 and 24 m depths. (Sample sites enclosed by broken line).

Model B - Biomass estimate was calculated using the samples from the 1 and 24 m depths.

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